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STATIC CHARACTERISTICS OF THERMAL HUMIDITY CONVERTERS OF LIQUID MATERIALS IN CONTINUOUS FLOW

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Annotation: Thermal systems with distributed heat sources based on a pipeline segment with radial holes are proposed for the development of designs of thermal humidity converters for liquid materials. Across the liquid flow there are tubular arguments with cylindrical heat-sensitive elements, on the surface of which the heating element winding was wound, which significantly increased their sensitivity, speed, reliability and allowed the use of standard semiconductor heat-sensitive elements.

Keywords: humidity, sensitivity, heating systems, performance, reliability, heating element, heat sources, thermosensitive element.

Аннотация: Суюқ материалларнинг намлигини иссиқлик ўзгарткичлари конструкцияларини ишлаб чиқиш учун радиал тирқишли ўтказиш қурулини бўлаги асосида иссиқликнинг тақсимланган манбаларига эга иссиқлик тизимлари таклиф этилган. Цилиндрсимон иссиқликка сезгир элементларга эга қувурли узаткичлар суюқ материал оқимида қўндаланг жойлашган, унинг юзасига эса қиздириш чўлғами ўралган бўлиб, ўзгарткичнинг сезгирлиги, тезкорлиги, ишончлилигини сезиларли даражада оширишга олиб келади ва стандарт яримўтказкичли иссиқлик сезгир элементларидан фойдаланишга имкон беради.

Таянч сўзлар: намлик, сезгирлик, иссиқлик тизимлари, тезкорлик, ишончlilik, қиздириш элементи, конструкция, иссиқлик манбаи, иссиқлик сезувчи элемент.

Аннотация: Для разработки конструкций тепловых преобразователей влажности жидких материалов предложены тепловые системы с распределёнными источниками тепла на основе отрезка трубопровода с радиальными отверстиями. Поперек потока жидкости расположены трубчатые доводы с цилиндрическими термочувствительными элементами, на поверхность которых была намотана обмотка нагревательного элемента, что существенно повысило их чувствительность, быстродействие, надёжность и позволило использовать стандартные полупроводниковые термочувствительные элементы.

Ключевые слова: влажность, чувствительность, тепловые системы, быстродействие, надёжность, нагревательный элемент, конструкция, источник тепла, термочувствительный элемент.

Introduction.

In the modern world, special attention is paid to the creation and modernization of measuring equipment and quality control in order to produce high-quality products with the lowest energy, raw materials and time costs. Currently, one of the leading roles is assigned to methods and devices for the automatic control of the moisture content of liquid materials to ensure product quality in the chemical, petrochemical and food industries. All over the world, the issues of automatic control of existing technological processes in various spheres of the national economy, improvement of methods and technical means of control, including methods and control algorithms, as well as improving their technical characteristics of elements and devices, expanding their functionality and design improvements. In the developed countries of the world, in particular in the USA, England, Germany, France, Czech Republic, Japan, Russia, China, Belarus and other countries, special attention is paid to the improvement of technical means of control and management of technological and production

parameters, which increase production efficiency on the basis of integrated automation of production processes and technologies. At the same time, it becomes important to increase the sensitivity, accuracy and speed of control system converters in technological processes related to the control of liquid flows, to reduce the error in measuring the flow rate of asymmetric liquid flows, to increase reliability under extreme operating conditions, and to reduce weight and dimensions.

Research methods and results obtained.

In the development of thermal converters for moisture content in liquid materials, the theory of measurements, analysis and processing of experimental data, the theory of information-measuring systems, methods of organizing an experiment and the physical foundations of obtaining measurement information using primary converters were applied.

Figure 1. the design of a thermal converter for the moisture content of liquid materials is shown, which in principle can operate in several stationary and dynamic modes [1,2].

On the basis of mathematical models of heat converters with lumped and distributed sources, the statistical characteristics of thermal converters of moisture content of liquid materials under stationary and dynamic modes of operation.

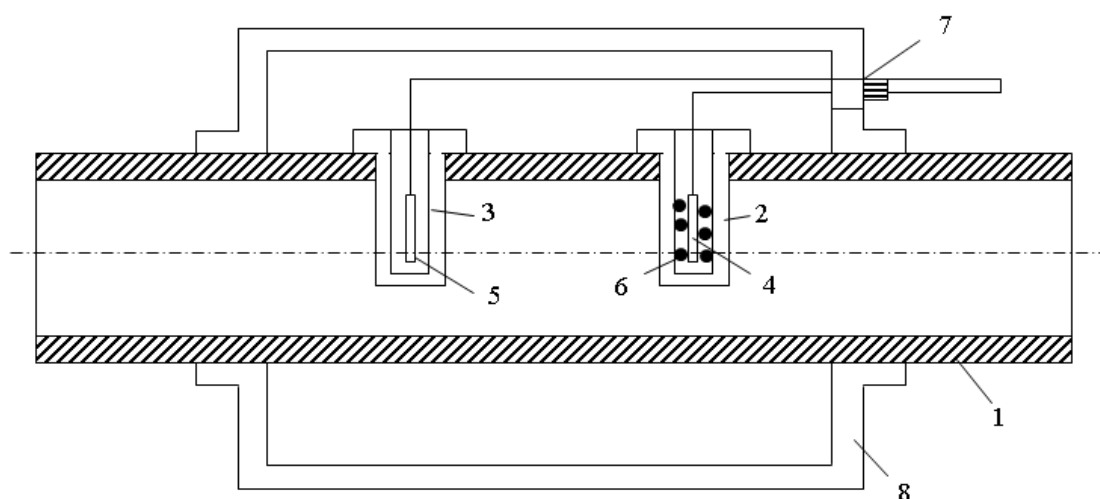


Fig. 1. Design of a thermal converter of moisture content for liquid materials:

1-pipeline with a flow of liquid materials; 2-heat conductor (probe) main; 3-heat conductor (probe) additional; 4-main thermosensitive element; 5-additional thermosensitive element; 6-heating element; 7-bumblebee connector for outputting wires of temperature-sensitive and heating elements; 8-sound thermal conversion enclosure.

For the considered thermal converter of moisture content of liquid materials, the main conditions for the design are:

- the heating element must be low-inertia, provide a sufficient heat flux that spreads along the heat pipe and enters into heat exchange with the flow of liquid material.
- the heating element must be suitable for stationary and non-stationary modes of operation of the thermal converter.
- the thermosensitive element should also be low-inertia, or small dimensions and high sensitivity.
- a cylindrical electric wire must also have small geometric dimensions and must be made of a material with high thermal conductivity and low heat capacity.

A feature of the considered heat converters is that the temperature has a distributed character along the heat conductor and depends both on the type of the heating element (heat source) and on the controlled moisture content of the liquid material, which describes the heat conductor of the transducer in the form of a stream during heat exchange at a constant v flow rate ($V=\text{const}$). The above is required

to analyze the thermal system of the considered transformation of such a research method, which takes into account the calculation of the temperature $T(x)$ of the heat flux $\Phi(x)$. Existing methods in the field of the theory of heat conduction, which make it possible to solve these problems. According to this principle, the distribution of $T(x)$ and $F(x)$ of the thermal system of detuned converters are expedient to investigate on the basis of the theory of thermal converters with distributed changes, while the matrix method on the theory and thermal stability is most effective for analyzing the main characteristics of thermal converters of moisture in liquid materials [3.4].

Matrix equations for determining $T(x)$ and $\Phi(x)$ along the heat pipe are

$$\begin{vmatrix} T(x, p) \\ \Phi(x, p) \end{vmatrix} = \begin{vmatrix} A(x, p) & B(x, p) \\ C(x, p) & D(x, p) \end{vmatrix} \begin{vmatrix} T(0, p) \\ \Phi(0, p) \end{vmatrix}, \quad (1)$$

$$A(x, p) = ch\gamma[(p)x]; B(x, p) = Z(p)sh[\gamma(p)x]; C(x, p) = \frac{1}{Z(p)}[sh[\gamma(p)x];$$

$$D(x, p) = ch[\gamma(p)x].$$

$$\gamma(p) = \sqrt{r(cp + g)}; Z(p) = \sqrt{\frac{r}{(cp + g)}}.$$

Thermal parameters per unit length:

1) Conductivity:

$$g = \alpha \pi d, \quad (2)$$

where: α – coefficient of heat sensor from heat pipe to flow; $\pi = 3,14$; d – diameter of the cylindrical heat pipe;

2) Resistance of the heat conductor;

$$r = \frac{1}{\lambda_{tp} F_{tp}}; \quad (3)$$

where: λ_{tp} – thermal conductivity of the heat conductor material; F_{tp} – the area of the material heat pipe;

Heat pipe capacity:

$$C = \rho C_p F, \quad (4)$$

where ρ – heat conductor material density; C_p – increased heat capacity of the heat conductor material; F – the area of the transverse series of the heat conductor.

$T(0, p)$, $T(x, p)$, $\Phi(0, p)$, $\Phi(x, p)$ - operator values of quantities:

$T(0, \tau)$, $T(x, \tau)$, $\Phi(0, \tau)$, $\Phi(x, \tau)$.

Based on the equations for determining $T(x)$ and $\Phi(0)$, we will get

$$T(x, p) = T(0, p)ch[\sqrt{r(cp + g)}x] - \Phi(0, p)\sqrt{\frac{r}{(cp + g)}}sh[\sqrt{r(cp + g)}x]. \quad (5)$$

and

$$\Phi(x, p) = -\frac{T(0, p)}{\sqrt{\frac{r}{(cp + g)}}}sh[r(cp + g)x] + \Phi(0, p)ch[r(cp + g)x]. \quad (6)$$

The statistical characteristic of the thermal converter (Fig. 1) at a constant heating rate $R_{ne} = \text{const}$ is determined on the basis of formula (1). To do this, first of all, it is necessary to determine the dependence of the relative change in the main thermistor $\varepsilon_1 = \Delta R_{T1}/R_{T1}$ on the change in humidity W in a given range. $W = W = [O, W_{\text{МОБЛ}}]$ liquid material.

As the investigated liquid material, a mixture of glycerine with water is chosen, which is well studied from the point of view of thermophysical characteristics and is widely used in various technological systems [5, 6].

Based on the data from [7, 8], the dependence of the thermal conductivity λ_{lm} of a mixture of glycerine with water was determined, which is shown in Fig.2.

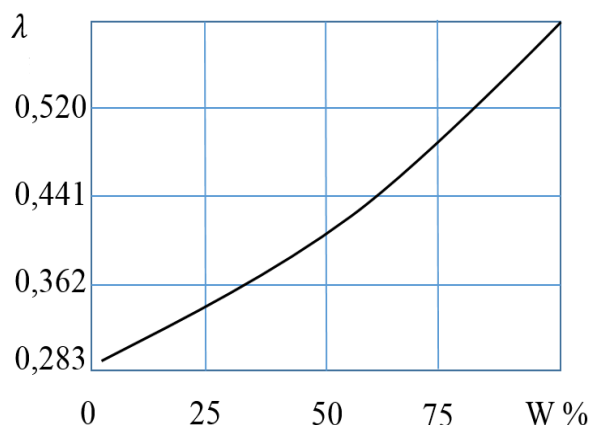


Figure: 2. A graph of dependence $\lambda_{jm} = f(w)$ for a mixture of glycerine with water at a temperature $T_0 = 20^\circ\text{C}$.

It was shown above that the Reynolds criterion (R_e) is determined by the formula

$$R_e = \frac{Vd}{\gamma}; \quad (7)$$

where: V – fluid flow rate; d – probe diameter. γ – coefficient of kinematic viscosity.

For the selected parameters of the converter at a temperature of $T=20^\circ\text{C}$, with liquid flows in the form of water, we have the values, R_e at speeds

$$V=0,05\text{M/C} \quad (8)$$

$$R_e = 153,8 \quad (9)$$

This provides a laminar flow regime with a constant fluid velocity V in the measuring section of the heat transducer and meets the requirement for optimal sensitivity.

Based on the above considerations, all structural elements of the thermal converter were manufactured.

Thus, for values $5 < R_e < 1000$, based on formula (8), we have for $V = 0.05$ m/s.

$$Nu = 0,50 \cdot 153,8^{0,5} \cdot 9,5 \cdot 0,36 \left(\frac{9,5}{9}\right)^{0,25} = 14,71 \quad (9)$$

$$\alpha = Nu \frac{\lambda_{jm}}{d} = 14,71 \cdot \frac{0,58}{0,004} = 2132,95 \quad (10)$$

We even determine the values α at different values of W (Fig. 2) to estimate the temperature difference ΔT between the main temperature-sensitive R_{t1} and the auxiliary temperature-sensitive R_{t2} , we use the formulas [11]

$$\Delta T = \frac{I_{he}^2 \cdot R_{he}}{\alpha_w \cdot F}, \quad (11)$$

where: I_{he} , R_{he} Electric current and resistance of the heating element; α_w values of the heat transfer coefficient at different humidity; F is the area of heat exchange between the main probe with R_{t2} and the flow of liquid material.

To ensure the maximum sensitivity of the thermal humidity converter, it is necessary to have sufficient heating power P_{he} and the optimal value α of and F in formula (11). To ensure sufficient power P_{me} , we select a heater from high-resistance wires (nichrome, manganin) and, taking into account the geometric dimensions of the thermosensitive element, we wind the heating element onto the surface of the thermosensitive element, in the quality of which a semiconductor thermistor of the MMT-1 type with a diameter $d_{te}=2,8 \cdot 10^{-3}$ and which is installed inside the probe from a copper tube $d_3=4 \cdot 10^{-3}$, which generally provides the minimum size of the probe with a temperature sensitive element [7,8,15].

Figure 3 shows the dependence $\Delta T=f(w)$ for different types of heating element Iwe. The highest sensitivity takes place, as shown above, at a current $I_{we}=0.2A$. To develop a thermal converter of the resistance of a liquid material, a heating element was manufactured and manganin wires with a resistance of $K_{he}=60$ ohms. At a zero value of the moisture content of the liquid material (solution of glycerin with water) $W=0\%$, the resistance of the main dust-conducting thermistor with the heating element turned on is $R_{t2}=4.88$ k Ω [13, 14].

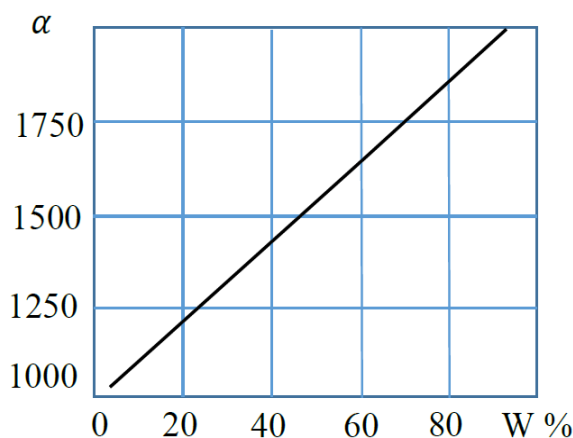


Figure 2. Dependence of the cooling coefficient α on the moisture content of the liquid material W .

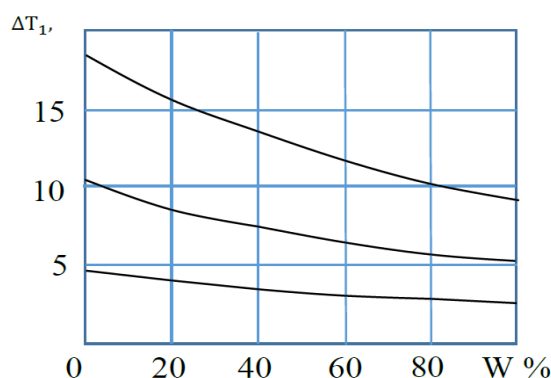


Figure 3. Dependence of the temperature difference ΔT on W at the heating current value: 1-0.2A; 2-0.15A; 3-0.1A.

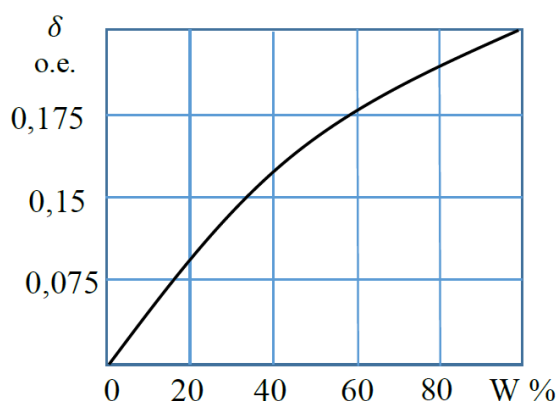


Figure 4. Dependency graph $\epsilon=f(W)$.

$$U_{\text{блх}} = U_M \frac{K}{(K+1)^2} \epsilon_1 \quad (12)$$

The value of the output voltage of the bridge measuring circuit in accordance with the formula (12) is shown in Fig. 5

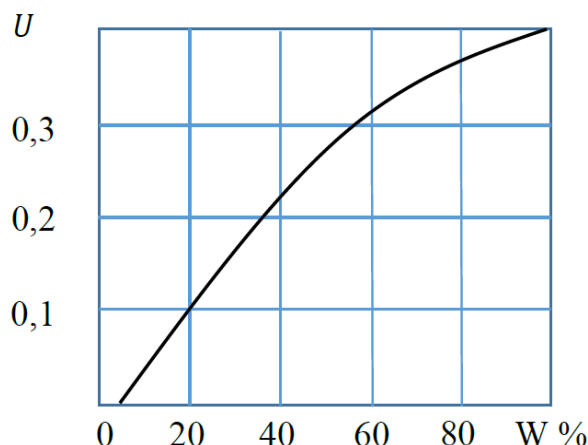


Figure 5. Static characteristic of the thermal humidity converter at $P = 2.4 \text{ W}$.

In the considered heat converters in the mode $P_{he} = \text{const}$, the heating current I_{he} is kept constant ($I_{he} = \text{const}$). This mode of operation of thermal converters of moisture content of liquid materials is very simple in technical implementation and convenient in systems for automatic control of the moisture content of liquid products in the corresponding chemical and technical processes [8,9,12].

The considered thermal converters of moisture content of liquid materials can also operate in the mode of alternating current heating of heating elements ($I_{he} = \text{Var}$), when a constant temperature difference (ΔT) between the main R_{T2} and additional R_{T1} semiconductor resistance thermometers is maintained in the bridge measuring circuit, as shown in Fig. 6.

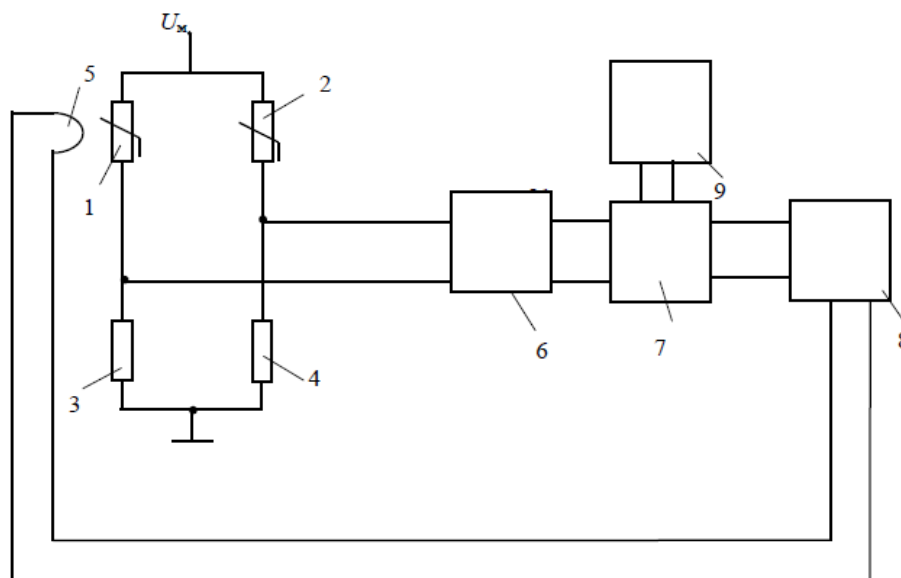


Figure 6. Bridge measuring circuit of a thermal converter of moisture content of a liquid material operating in the following mode $\Delta T = \text{const}$:

1,2 - main and additional semiconductor resistance thermometers; 3,4 - constant resistance; 5 - heating element; 6 - voltage amplifier; 7 - amplifier; 8 - ammeter; 9 - problem book.

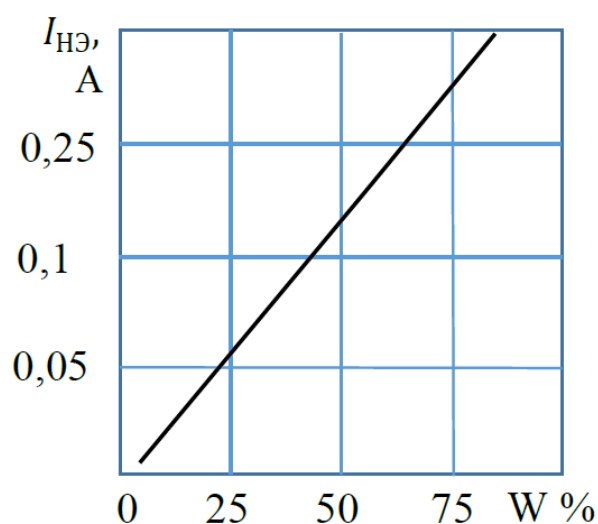


Figure 7. Static characteristic of the thermal converter of moisture content of liquid material in the mode $I_{he}=V_a$.

The mode of operation of thermal converters of moisture content of liquid materials with discrete switching on and off of the heating element, shown in Fig. 8.

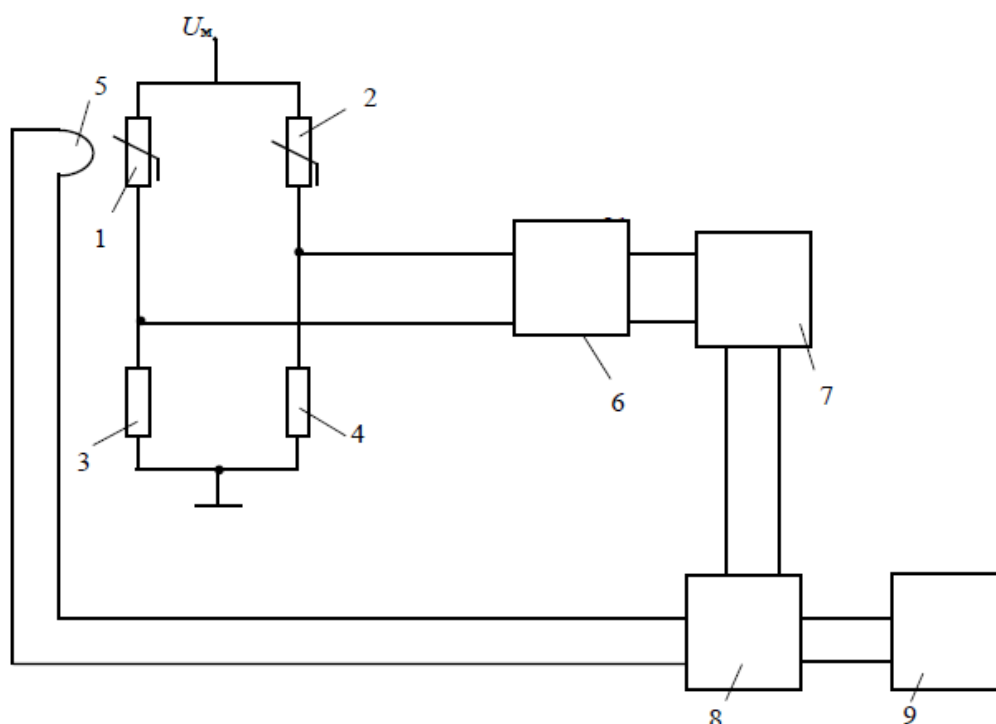


Figure 8. Bridge measuring circuit of a thermal converter of a liquid material operating in discrete on and off mode of the heating element:

1,2 - main and additional semiconductor resistance thermocouples; 3,4-constant resistance; 5- heating element; 6 – amplifier; 7- trigger; 8- electronic key; 9-indicator element.

As shown in (Chapter 1), with short-term heating of a thyristor switch 8 by a 5-ohm heater, the heating time δ_n (Fig. 9) is practically constant and with a change in the moisture content of the liquid material W , only the cooling time δ_{ox} changes as shown in Fig. 9.

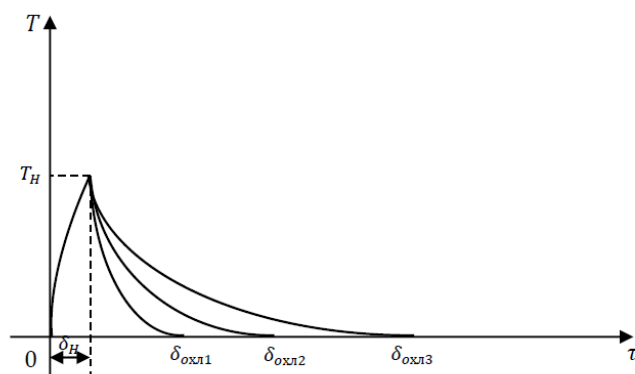


Figure 9. Graphs of heating time change T_H cooling time δ_{ox1} , δ_{ox2} u δ_{ox3} at different values of moisture content of liquid material W_1, W_2, W_3 .

The cooling time constant of the heat converter is determined [10,12,16] by the formula

$$T = \frac{pc_p I}{\alpha_{AD}} \quad (12)$$

Taking into account the dependence $\alpha=f(w)$ in Fig. 10, the graph of the dependence of the time constant current W will have the form:

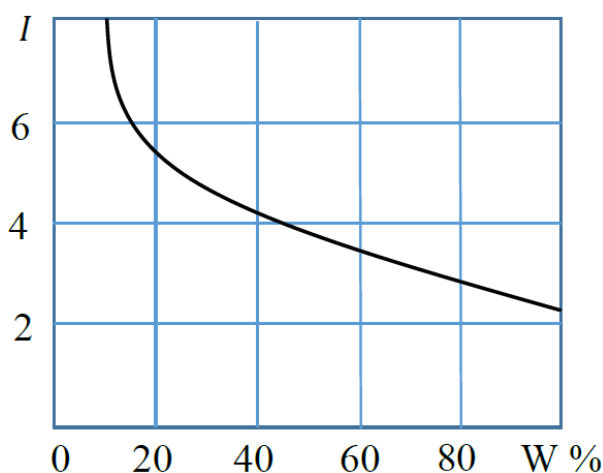


Figure 10. A graph of the dependence of the thermal converter when controlling the moisture content of a solution of glycerin with water $T = f(W)$.

Conclusion

It is shown that thermal systems with distributed heat sources based on a section of a pipeline with radial holes, in which tubular arguments with cylindrical thermosensitive elements are located across the flow of liquid material, on the surface of which a heating element winding is wound, are most suitable for the development of designs of thermal converters of moisture content in liquid materials. which significantly increases their sensitivity, speed, reliability and allows the use of standard semiconductor temperature-sensitive elements.

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